

PATENT SPECIFICATION

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COMPLETE SPECIFICATION

DRAWINGS ATTACHED

Improvements in and relating to Optical Apparatus

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by statute, of 1, Tilney Street, London, W.1., do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to optical apparatus and in particular to an optical device by means of which the optical path of a ray or narrow beam of light may be increased to many times the physical length of the device.

15 If a ray or narrow beam of light lying in a plane transverse to a pair of inwardly facing plane reflectors at 90°, (i.e. lying in a plane normal to the line of intersection of the planes of the reflectors) enters between
2) them in a direction which is within certain limits, it will after twice being reflected emerge parallel with its direction of entry but lateral displaced in the plane in which it entered. If two such 90° pairs of plane
25 reflectors are set with the reflecting faces of one pair facing the reflecting faces of the other pair, and with their transverse planes parallel or approximately so, a ray or narrow beam entering the system so
30 formed in a direction which is not parallel with the plane joining the lines of intersection of the two pairs will be reflected to and fro in succession in parallel paths between the pairs of reflectors, undergoing different lateral displacements each time, and the present invention consists in so relatively
35 disposing the pairs and the direction of entry of the ray or narrow beam that the ray or narrow beam is reflected at least six times
40 and thus has its path increased by at least three times the distance between the pairs before escaping from the system. Preferably the planes bisecting the 90° angles of

the two pairs are parallel and the direction in which the ray passes to and fro is parallel with these planes because then each pair can be symmetrical and the bulk of the device is reduced, other conditions remaining the same.

Each pair may be a pair of simple plane reflectors with air between them but a more convenient practical arrangement is to constitute each pair of the faces bounding the right angle of a 90° prism. A prism has the advantage that the reflecting faces cannot go out of adjustment in relation to one another and it can also easily be provided with protection and will not vary optically with time because the reflection depends on the optical qualities of the glass or other transparent material, and not of a thin coating thereon.

In this case it is desirable that the direction of the rays between the prisms should be normal to the hypotenuse faces because there will then be no refraction at these faces. However, this is not essential and the refraction at entry will always be exactly matched by the refraction at exit so that parallelism of the rays will be maintained. When prisms are used either the transverse planes of each should be parallel or the ray should only enter normally, but in the latter case some degree of skewing of one prism in relation to the other can be permitted but then the ray after each passage through one prism will be displaced into a different transverse plane of the other prism. With pairs of reflectors instead of actual prisms these limitations do not apply because there is no actual hypotenuse face at which refraction will occur if a ray does not enter or leave normally. However, even with actual prisms very slight skewing can be tolerated in practice even when the ray does not enter normally, with the great practical advantage that heavy rigid mountings for holding the

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prisms with respect to one another can be dispensed with, with consequent further advantages in the case of portable instruments.

5 In any case, if the path of the ray is followed it will be found that it passes to and fro between the two pair of reflectors or prisms with a different lateral displacement each time and that unless it escapes previously from the system, after a certain number of cycles the displacement reverses and the ray will in general finally clear the system.

For the sake of convenience and economy of material, preferably the prisms are of isosceles form, that is, the two side faces are at 45° to the base, the transverse planes are substantially parallel and the ray enters the first prism substantially normally to its base, so that the path of the ray always lies substantially in one plane.

It will be assumed hereinafter that a pair of prisms is used but any modifications necessary for the case of two plane reflectors in each pair will be readily understood by those skilled in the art.

The invention will be further described with reference to the accompanying drawings, in which:—

30 Fig. 1 shows only two 90° prisms 11 and 12 arranged with their base (hypotenuse) faces 13, 14, parallel. The prisms are shown of the preferred isosceles form, i.e. the base angles are of 45° and the ray between the prisms is normal to the faces 13, 14 so that there is no refraction where the ray passes through these faces. The offset distance which is marked d is measured between two planes p_1 and p_2 passing through the apex edges of the two prisms extending parallel to the entering ray r . In this particular case these planes p_1 , p_2 are in fact the planes which bisect the 90° angle of the prisms, but though this arrangement is preferred since it economises in material, the invention is not restricted to it, and it is not even essential that the faces 13, 14, should be parallel. The ray r enters the prism 11 at a distance b from the plane p_1 , that is to say on the opposite side of this plane to the offset d . After entering the prism 11, the ray is twice reflected at the surfaces 15, 16, in succession and emerges at a distance b from the plane p_1 , but on the opposite side, and it therefore enters the second prism 12 at a distance $b-d$ from the plane p_2 , and after twice being reflected in succession at the surfaces 17, 18, of the prism 12 emerges at a distance $b-2d$ from the plane p_1 . Thus, after making one circuit through the system the ray has been displaced laterally by a distance $2d$.

After a number of half circuits dependent upon the magnitude of the offset distance d the ray will emerge from one of the prisms

between the planes p_1 , p_2 , in which case the ray will now become incident on the other side of the apex of the other prism, and this will cause the ray to take a path in which it circulates to the opposite hand. In general, if the incident ray enters the first prism close to one base angle on the opposite side to the offset the ray in its first series of circuits will approach closer and closer to the vertex plane of the first prism until it remains on this side of the vertex plane of the second prism and thereafter in its further circuits it will move further and further away from the vertex plane of the second prism.

Fig. 1 illustrates the general case, the ray r entering quite close to one of the base angles of the prism 11 and as has already been mentioned on the opposite side of the plane p_1 to the offset d ; also the value of d has been made relatively large so that the ray emerges from the prism 11 between the planes p_1 and p_2 after only one-and-a-half circuits, whereafter it moves further and further away from the plane p_2 , finally emerging from the system after only another one-and-a-half circuits, making three circuits in all, or in other words undergoing 12 reflections and making seven passages between the prisms i.e. an increase of the path, ignoring the parts of the path within the prisms, of six times the distance between the prisms. However by suitably selecting the offset d and the distance b the number of circuits can be increased without difficulty, at any rate up to a value of 10. With an integral number of circuits the ray finally emerges as in Fig. 1 in the same sense as that in which it entered, but if the sense is unimportant, the system may be arranged so that the ray emerges after an odd number of half circuits.

Consideration will show that though there is a lateral displacement $2d$ at each circuit, the total lateral displacement will not be equal to the product of the number of circuits and $2d$ if the second series of circuits as well as the first is used.

It will be clear that the invention is not confined to arranging the path so that in the first series of circuits the ray approaches close and closer to the plane p_1 , and in the second series it moves further and further away from the plane p_2 . An obvious alternative is to reverse the direction of the ray. Again, only one series of circuits could be used and this might be traced by a ray entering as in Fig. 1 and emerging when close to the plane p_2 either in the original sense or the opposite sense, or it might be traced in the reverse direction.

It is to be understood that though vertex edges are referred to above, the prisms do not necessarily come to a defined vertex at the 90° corner, though generally speaking if the whole of the paths described above are

employed the prism will have to be nearly if not quite complete at this corner to provide for the reflection of the ray where it is close to the plane $p1$ or $p2$. As shown in Fig. 1 the ray at entry clears the base corner of the prism 12 and at exit clears the base corner of the prism 11, but if the dimensions selected so require, either of these corners can be cut off sufficiently to clear the ray without preventing its reflection at the surface of the prism in the adjacent limb of its path.

If only the first half of the path, that is to say, those circuits in which the ray comes closer to the planes $p1$, $p2$ is used, by cutting off the vertex of the one prism on a plane parallel with its base as indicated at 19 in Fig. 2, the ray can be arranged to emerge through this cut surface. In Fig. 2 the ray r is shown emerging after one and a half circuits in the opposite sense to that in which it entered, thus being reflected six times and having its path increased (ignoring the parts of the path within the prisms) by three times the distance between the prisms. It will be clear that as before by varying the values of b and d the number of half circuits can be increased and also that the ray could take the reverse path.

Alternatively to the ray reaching the system and leaving it in a direction parallel with the planes $p1$ and $p2$, reflectors and/or refracting prisms can be used for bringing a ray coming from another direction into parallelism with the planes $p1$, $p2$, and similarly for redirecting it when it leaves the system. Examples will be described below. It will also be understood that though the term ray has been used, similar action will be obtainable with a narrow, parallel beam of light, which would usually be used in an optical instrument making use of the device according to the invention.

A particular use for the invention is for modifying the construction of the Jamin interferometer used for estimation of gas composition by measuring the variation in refractive index of a column of test gas compared with a column of gas of standard composition. Variations in refractive index are very small and accuracy of measurement involves long columns. The present invention, by enabling the same beam to be passed many times through the same column of gas, enables the column to be reduced in length for a given standard of accuracy.

The same prisms can be used for producing a corresponding multiple passage of a beam through a reference gas cell. All that is necessary is to make the prisms of adequate depth, measured parallel to the vertex edge, and to provide a dividing deck between the two gas cells.

In view of the relative offset of the two prisms, it would be possible as described

above with reference to Fig. 1 for the beam to enter past the base corner of one and into the base face of the other and for the beam finally to leave in a similar manner. But it is generally more convenient to provide a dividing and recombining plate set between the prisms as shown in Figs. 3 and 4.

In these figures, two identical gas cells 31 and 32 are arranged side by side and parallel and are separated from one another by a deck 33 which extends over the entire distance between the prisms 34 and 35. A transparent dividing plate 36 and recombining plate 37 operating on known principles are arranged between the prism 34 and one end of the gas cells at an angle about 45° to the longitudinal axis of the device, the plate 36 to deal with the entering ray and the plate 37 to deal with the emerging ray. These plates must not intercept the rays passing to and fro between the prisms but as it is convenient for manufacturing reasons to make them in one piece, a single piece of glass may have an aperture in it to clear the rays passing to and fro, leaving two cross bars 38 joining the actual dividing and recombining plates 36, 37. However, if preferred two separate short plates may be used.

In using the dividing plate serves to split an incoming beam into two one above and the other below the deck 33. Each of these beams circulates in accordance with the invention by the action of the prisms 34, 35, the limbs of its path traversing the corresponding gas cell. When the beams finally emerge they are re-combined by the plate 37 and the combined beam can be examined to ascertain the interference between the two in the manner usual in the Jamin interferometer. The arrangement of the apparatus ensures that the optical length of the path of both beams, both through the gas cells and elsewhere is identical, but since the beams traverse the cells a plurality of times, the overall length can be reduced for a given accuracy or, alternatively, greater accuracy can be obtained for a given length of apparatus. By arranging for the offset distance d to be changed, which can be done by making one of the prisms slidable parallel with its base surface, the number of passages of the beams through the gas cells can be varied.

In an alternative arrangement shown in Fig. 5 the prisms are divided on the same plane as the dividing deck (not shown) between the gas cells (not shown) and the pair of prisms 41a, 42a dealing with the rays passing through one of the gas cells is laterally displaced a short distance in relation to the other pair 41b, 42b.

A short dividing plate 43 divides the incident beam 44 into two beams laterally separated by a short distance. The one beam

44a is re-directed by a small 45° parallelogram prism 45 into the prism 41a, whilst the beam 45 into the prism 41a, while the other beam 44b directly enters the prism 41b. The two beams circulate in accordance with the invention passing a plurality of times through the gas cells. Finally, the beam 44a passes directly out of the prism 42a and directly into a combining plate 46, while the beam 44b after finally emerging from the prism 42b is re-directed by another 45° parallelogram prism 47 into the combining plate 46, so that the two beams 44a and 44b are re-combined. Except for the passage through the two gas cells it will be seen that once again the two paths of the divided beam are identical.

Fig. 6 illustrates the application of the invention to a telescope whereby the overall length can be reduced to a fraction of the focal length of the objective indicated at 51. Here two prisms arranged in accordance with the invention are shown at 52, 53, the prism 53 being truncated to allow the ray to emerge in a similar manner to that described above with reference to Fig. 2. For the sake of simplicity the ray is shown as having only three limbs before emerging from the prism 53, but it will be understood that in practice the prisms are dimensioned to produce five or some higher odd numbers of limbs. The ray emerging from the prism 53 passes through a pair of erecting prisms 54, 55, and finally reaches the eyepiece 56. It will be seen that the prisms 52, 55 are of similar form and, if desired, they may be made integral.

It will be clear that the application of the invention to a telescope is not confined to the prisms being arranged so that the ray emerges after the first series of circuits, as in Fig. 2 above. The prisms may be arranged as in Fig. 1, so that the ray makes both series of circuits and finally clears the base angle of one of the prisms, this base angle being, if necessary, cut off as above described. The ray would then pass through two erecting prisms as described with reference to Fig. 6. Also, as above described, the second erecting prism can be combined with one of the prisms provided in accordance with the invention.

Since for a given eyepiece power the magnification of a telescope is proportional to the focal length of the objective, the invention enables a substantially higher magnification to be obtained for a given overall length.

As mentioned above, since the present invention depends on reflection at plane surfaces, pairs of plane reflectors can be used instead of 90° prisms, but for reasons also stated above prisms are generally preferable. The description also assumes that there is no relative skewing between the prisms but, as also explained above, a certain degree of

skewing can be tolerated. Similarly, the action is unaffected if the hypotenuse faces of the prisms are not exactly parallel, and is unaffected if the prisms are not isosceles.

It will also be understood that the distance *b* and *d* must be selected so that the ray does not at any time intersect the apex of the 90° angle of the prism or between the reflecting faces. By making the offset distance *d* adjustable the number of circuits the ray makes within the system can be varied.

WHAT WE CLAIM IS:—

1. An optical device by means of which the optical path of a ray or narrow beam of light may be increased to a multiple of the physical length of the device which comprises two pairs of inwardly facing plane reflectors at 90° set with the reflecting faces of one pair facing the reflecting faces of the other pair, and with the transverse planes of the pairs parallel or approximately so, the relative disposition of the pairs and the direction of entry of the ray or narrow beam being such that the ray is reflected at least six times and thus has its path increased by at least three times the distance between the pairs before escaping from the system.
2. An optical device according to claim 1 in which the planes bisecting the 90° angles of the two pairs are parallel and the ray or beam passes to and fro parallel with these planes.
3. An optical device according to claim 1 or 2 in which the reflecting faces are the faces bounding the right angle of a 90° prism.
4. An optical device according to claim 3 in which the prisms are isosceles prisms.
5. An optical device according to claim 3 or 4 in which the prisms are set with their base (hypotenuse) faces parallel.
6. An optical device according to any preceding claim in which the pairs of reflectors are arranged so that the ray or beam entering the system clears the edge of one reflector of one pair and the ray or beam leaving the system clears the edge of one reflector of the other pair.
7. An optical device according to claim 6 employing pairs of reflectors in prism form in which at least one base angle of one prism or both prisms is cut off to provide clearance for the ray or beam without preventing reflection of the adjacent limb of the path of the ray or beam between the prisms.
8. An optical device according to any preceding claim in which the ray or beam enters or leaves the system between the reflecting faces of one pair.
9. An optical device according to claim 8 employing pairs of reflectors in prism form in which the 90° corner of one or both prisms is truncated.